# Miniature Low Power S~lb]]~illi~]~ctcr-Wave Spectrometer for Detection of Water in the Solar System

Olga Boric-Lubecke*, *Member IEEE*, Richard F. Denning, Michael A. Janssen and Margaret A. Frerking, *Member IEEE*

Jet Propulsion Laboratory,
California Institute of Technology,
4800 Oak Grove Drive,
Pasadena, CA 91109-8099

**Currently with The Institute of Physical and Chemical Research, Sendai, Japan.*

Abstract - The mass and power Of a heterodyne spectrometer must be greatly reduced to satisfy small spare mission constraints. We report on a 220 GHz receiver, requiring less than 4.8 W, with a mass of 1.25 kg,. The mass and power savings arc achieved through reducing components to a minimum, while providing performance for a Martian atmospheric sounder.

## INTRODUCTION

The transformation of waler from ice to vapor is one of the most powerful forces for change on planets and small planetary bodies. [1 -2]. One of the strongest transitions of water, the ground state transition, occurs near 557 GHz, in the submillimeter wavelength region. A capable spectrometer operating in the vicinity of this line can address the needs of future Solar System exploration missions. For example, on Mars, such an instrument can characterize the nature and the dynamics of the planetary boundary layer by determining pressure, temperature, and humidity over diurnal and seasonal cycles with measurements of thermal spectral line emissions from CO (near 577 (i] Hz) and $H_2O$.

The mass and power typical of a heterodyne spectrometer must be greatly reduced to make it a viable candidate for small space missions. For instance, the Microwave Limb Sounder currently flying on the Upper Atmospheric Research Satellite, with three heterodyne radiometers, has a mass of 283 kg and a requires 162 W [3]. The Submillimeter Wave Astronomical Satellite, to be launched in 1997, has a total mass of 92.5 kg, and power of 60.7 W [4]. The Microwave Instrument for Rosetta Instrument anticipates 16.2 kg and 61 W [S], with two heterodyne receivers at 236 GHz and 562 GHz, and a full back-end spectrometer.

Here we report on a prototype instrument for detection of water throughout the solar system, with the total mass of 1.25 kg (exclusive of telescope) and power of less than 4.8 W. The great reduction in mass and power was achieved through minimizing receiver components, while still maintaining adequate functionality for a Mars atmospheric sounding instrument. Frequency scanning is achieved by tuning the local oscillator (LO), and thus eliminating the need for filter banks or the backend spectrometers. In this case, frequency multiplexing was traded for low mass and power, hence increasing the time required to obtain a spectrum of the atmospheric emission, acceptable for Mars sounding applications. The mixer downconverted signal is detected at the first intermediate frequency (IF) so that the further downconversion is not necessary, which removes low frequency LO sources and amplifiers. Novel frequency control eliminates the need for a phase-locked loop system as well as an active thermal control system.

## EXPERIMENTAL RESULTS

Since the 557 GHz mixer and associated multiplier chain are still under development, we have prototyped a 220 GHz version of the instrument to verify the concept. The block diagram of the 220 GHz radiometer is shown in Fig. 1, and the picture of the prototype in Fig. 2. The heterodyne receiver uses a subharmonic planar Schottky diode mixer [6], an in]'temperature compensated GUNN oscillator at 110 GHz tunable over 0.5 GHz for the LO, and an IF at 8 GHz with a 10 MHz bandpass filter. Measured mass and power of this receiver are given in '1'able 1. Off-the-shelf amplifiers were used in this prototype. Additional power reduction, in excess of 1 W, will be achieved by use of MMIC amplifiers. Projected mass and power of 560 GHz receiver, with MMIC amplifiers, are shown in Table 1 as well. Here, the s~lbll~illil~lc[cl.-wave LO at 280 GHz uses a 140 GHz GUNN to drive a multipler. Two detection channels are required, since currently available 140GHz GUNN oscillators cannot be bias tuned for wide enough range to detect the $H_2O$ and CO lines simultaneously.

The low power LO frequency control is provided through a feedback loop, which consists of a temperature sensor mounted on the GUNN oscillator, a microcontroller, and a programmable voltage supply. The bias voltage is adjusted to compensate for the frequency drift due to the temperature change, eliminating the need for the pbase-locked loop system and the active thermal control system [7]. Accuracy of couple of MHz was achieved, which is sufficient for a detection with a 10 MHz wide filter. As a check, symmetric measurements on both sides of spectral lines will be used to monitor the LO frequency. A microprocessor also controls the GUNN bias voltage to scan the signal through the IF filter. The IF is detected directly at the 8 GHz. A detector at this frequency is not an issue, while low 10ss filter is what limits frequency resolution. For applications with higher resolution this approach is feasible, but requires filter development.

The prototype receiver was tested using a laboratory signal source, a PC as a controller, and a spectrum analyzer as a detector. To demostrate the LO tunability, a fixed signal was observed at 210.9 GHz with three different LO settings of 109.445 GHz, 109.450 GHz and 109.455 GHz. The output of the mixer is shown in Fig. 3 a. To demostrate the functionality of the end-to-end receiver, the frequency of the laboratory signal was changed, and the LO frequency adjusted accordingly to always produce an IF at 8 GHz. Output of the IF filter in shown in Fig. 3 b for signal at 210.9 GHz, and 1.() at 109.450 GHz.

## CONCLUSIONS

We have demonstrated more than a factor of 10 reduction in mass and power for a heterodyne receiver system, enabling the use of this powerful 1001 for future space missions. The 220 GHz radiometer with a total mass of 1.25 kg and power of less than 4.8 W was designed, assembled and tested. Further power reduction in excess of 1 W will be achieved by using MMIC amplifiers.

## ACKNOWLEDGMENT

We would like to thank R. J. Dengler, T. C. Koch, M. J. Mahoney, D. O. Muhleman, J. E. Oswald, P. f]. Siegel, and U. Zimmerman for valuable discussions, and A. B. Hubbard and A. J. Pease for technical support. This research was sponsored by the National Aeronautics and Space Administration, office of Space Sciences.

## REFERENCES

1] C. B. Farmer, D. W. Davis, A. 1.. Holland, 1). D. LaPorte, and 1'. E. Doms, "Mars water vapor observations from the Viking Orbiters," *J. Geophys. Res.*, Vol. 82, pp. 4225-4248, 1977.

2] F. L. Whipple, *Astrophys. J.*, Vol. 111, p. 375, 1950.

3 F. "I'. Barath et all, "The Upper Atmosphere Research Satellite Microwave Limb Sounder Instrument," *J. Geophys. Res.,* Vol. 98, no. D6, pp. 10 75 -10762, 2, June 20, 1993.

[4] Private communication, G. Chin.

[s ] Private communication, M. A. Frerking.

[6] 1. Mehdi at all, "Planar GaAs Schottky Diodes Integrated with Quartz Substrate Ciruitry for Waveguide Subharmonic Mixers at 215 GHz," 1994 IEEE MTT-S Digest, pp. 779-782.

[7 ] O. Boric-Lubecke, R. F. Denning, M. A. Janssen and M. A. Frerking, " Novel LO Frequency Control for a 230 GHz Radiometer with a 110 GHz GUNN oscillator,'" submitted to the Eight International Symposium on Space Terahertz Technology, March 25-27, 1997, Boston, MA.